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# INDUCTIVE TRANSMISSION OF ELECTRIC ENERGY

## TECHNICAL FIELD

This disclosure relates to inductive transmission of electric energy, for example, a circuit arrangement for supplying an electrical appliance with power and/or for inductively charging a battery.

## BACKGROUND

Devices for transmitting electric energy, such as electrical circuits, are known in the art. For example, DE 38 42 465 A1 discloses a switching controller for a d.c.-d.c. conversion which comprises an electronic switch and a series-resonant circuit (rather than an inductor). The switching controller oscillates with the resonant frequency of the series-resonant circuit and therefore has a particularly high efficiency if the electronic switch switches in the zero crossings of the current. The electronic switch is realized with two complimentary switching transistors that are controlled in antiphase. The control of the switching transistors is realized with a feedback circuit and input stages for the switching transistors that are not described in detail.

As another example, DE 40 15 455 A1 discloses a control circuit for an inverted rectifier that comprises a push-pull output stage with complementary transistors. The control of the transistors is realized with two electrically coupled control signals of mutually shifted potential. The connecting and disconnecting control signal edges are shifted by means of a delay circuit such that the initially switched-on transistor is switched off before the still switched-off transistor is switched on. This results in a relatively complex control circuit.

## SUMMARY

According to one aspect, an inductive electric energy transmission circuit includes: an oscillating circuit; a push-pull circuit including a first switching transistor and a second switching transistor that are configured to alternate a current flow through the oscillating circuit. The circuit arrangement also includes a control circuit including first and second control transistors configured to control the first and second switching transistors; and a frequency generator configured to generate an output signal adapted to drive the control transistors. With a low circuit expenditure, a high efficiency circuit arrangement for transmission of electric energy can be made available.

In some cases, the oscillating circuit is configured to oscillate at an oscillatory frequency substantially equal to a frequency of the output signal of the frequency generator.

In some cases, the output signal of the frequency generator includes a square-wave signal, i.e., if the frequency generator delivers a square-wave output signal.

In some embodiments, a control terminal of the first control transistor and a control terminal of the second control transistor are configured to receive the output signal from the frequency generator. Preferably, a control terminal of the first switching transistor is electrically connected to a first end of a resistor, and a control terminal of the second switching transistor is connected to a second end of the resistor.

In some implementations, a first capacitor is arranged electrically parallel to a main current path of the first control transistor, wherein a first end of the capacitor is electrically connected to the first end of the resistor; and a second capacitor is arranged electrically parallel to a main current path of the second control transistor, wherein a first end of the second capacitor is electrically connected to the second end of the resistor. Preferably, the first capacitor, the resistor, and the second capacitor form a series connection, wherein a supply voltage source is connected in parallel with the series connection. Due to these measures, one switching transistor can be switched off faster than the other switching transistor is switched on, thereby preventing the supply voltage source from being quasi short-circuited as a result of the first and second switching transistors being simultaneously switched on.

In some examples, the oscillating circuit includes an inductive coil. In this case, the inductive coil may form a primary coil of a transformer. Preferably, the primary coil can supply electric energy to a secondary coil of the transformer. The circuit arrangement can be used, for example, for supplying electric energy to a small electrical appliance that contains the secondary coil, preferably electric toothbrushes or electric razors that may also contain a battery.

One embodiment of a circuit arrangement configured for the inductive transmission of electric energy is illustrated in FIG. 1. Other embodiments are discussed in the following description.

## DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic diagram of circuit arrangement configured to inductively transmit electric energy.

**DETAILED DESCRIPTION**

The circuit arrangement illustrated in FIG. 1 includes two switching transistors in the form of complimentary field effect transistors (e.g., first switching transistor T2, and second switching transistor T4), the drain terminals of the first switching transistor T2 and second switching transistor T4 are connected to one another and to one end of an oscillating circuit including an inductor Lpr and a capacitor Cpr. The other end of the oscillating circuit and the source terminal of the n-channel field effect transistor (i.e., second switching transistor T4 are connected to ground. The source terminal of the p-channel field effect transistor (i.e., first switching transistor T2) is connected to the plus pole of a supply voltage source U1. The minus pole of the supply voltage source U1 is connected to ground. The circuit arrangement includes two additional control transistors in the form of complimentary field effect transistors (e.g., first control transistor T1, and second control transistor T3), the gate terminals of the first control transistor T1 and the second control transistor T3 are directly connected to the input of a frequency generator F that generates an output signal referred to ground.. The gate terminals of the first and second switching transistors T2, T4 are connected by means of a resistor R1. One end of the resistor R1 is connected to the drain terminal of the p-channel field effect transistor (i.e., the first control transistor T1), as well as to the plus pole of the supply voltage source U1 by means of the first capacitor C1. The other end of the resistor R1 is connected to the drain terminal of the n-channel field effect transistor (i.e., the second control transistor T3), as well as to ground by means of a second capacitor C2. The source terminal of the first control transistor T1 is connected to the plus pole of the supply voltage source U1. The minus pole of the supply voltage source U1 is connected to the source terminal of the second control transistor T3.

In another embodiment, the first and second switching transistor T2, T4 and/or the first and second control transistors T1, T3 can be complimentary bipolar transistors.

In another embodiment, the polarities of the supply voltage source and the transistors (i.e., the first and second switching transistors and the first and second control transistors) are reversed.

Other variations of the above-described embodiments lack the first and second capacitors C1 and C2, i.e., the function of these capacitors is respectively fulfilled by the gate-source capacitance and the base-emitter capacitance of the first and second switching transistors T2, T4.

The function of the circuit arrangement illustrated in FIG. 1 is described below. The first and second switching transistors T2, T4 are wired in the form of a push-pull stage and alternately connect the oscillating circuit to the operating voltage and to ground,

wherein the push-pull stage is controlled with square-wave signals by the first and second control transistors T1, T3. The first and second capacitors C1, C2 and the resistor R1 are provided in order to prevent that the switching transistors T2, T4 from simultaneously carrying a high drain current. For example, if the output signal of the frequency generator F is positive, i.e., if it approximately assumes the operating voltage, the second control transistor T3 is conductive and the first control transistor T1 is non-conductive. Consequently, the first switching transistor T2 is conductive and the second switching transistor T4 is non-conductive. When the output signal of the frequency generator F changes to ground, i.e., the reference potential, the first control transistor T1 and the second switching transistor T4 become conductive while the second control transistor T3 and the first switching transistor T2 become non-conductive. This causes the gate-source voltage of the first switching transistor T2 to drop with a time constant R'C', wherein R' refers to the track resistance of the now conductive first control transistor T1 and C' refers to the sum of the capacitance of the first capacitor C1 and the input capacitance of the first switching transistor T2. The gate-source voltage of the second switching transistor T4 simultaneously increases with a time constant R''C'', wherein R'' refers to the sum of the resistance of the resistor R1 and the track resistance of the now conductive first control transistor T1 and C'' refers to the sum of the capacitance of the second capacitor C2 and the input capacitance of the switching transistor T4. Assuming that C' is practically equal to C'', R'C' is much shorter than R''C'' because the resistance R' is much lower than the resistance R'', i.e. the switching transistor T2 is switched off faster than the switching transistor T4 is switched on. If the first and second capacitors C1, C2, the input capacitances of the first and second switching transistors T2, T4 and the track resistances of the first and second control transistors T1, T3 are approximately equal, one switching transistor consequently is always switched off faster than the other switching transistor is switched on. The time delay between switching on and switching off can be adapted to the switching and delay times of the first and second switching transistors T2, T4 by choosing the ratings of the first and second capacitors C1, C2 and of the resistor R1 accordingly.